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Soils of the Oraibi valley, Arizona, in relation to Plant Cover

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Abstract. In a previous paper (*Plateau*, 41, 2:61–71), the principal plant associations found in the Oraibi valley were described, and their bearing on Hopi agriculture outlined. This paper relates the plant associations found in the valley to the soils on which they grow.

As the word *loam* figures prominently in the discussion that follows, we may begin with a definition. The word is derived from the root *lai-*, 'to be sticky', and is defined as "a rich soil, composed chiefly of clay and sand with an admixture of decomposed vegetable matter" (*Oxford English Dictionary*), or alternatively, as "a clayey, hence moist, earth" (Partridge, *Origins*, p. 357). From these definitions, two points emerge: to qualify as a *loam*, a soil must contain a fair proportion of clay, and further, the moisture-retaining capacity of a soil is related to its clay content.

All soils are made up of four kinds of mineral particles, combined in different proportions, with or without an admixture of humus. The four kinds of mineral particles are defined by their relative size (Brade-Birks, p. 142):

Coarse sand	2.0 - 0.2 mm.
Fine sand	0.2 - 0.02 mm.
Silt	0.02 - 0.002 mm.
Clay	less than 0.002 mm. in diameter

Soils are classified according to the percentage of the different kinds of mineral particle which they contain: the simplest classification, and the one most useful for our purpose, being that which grades soils by their clay content. If we regard a given soil sample as divisible into 12 parts, then a soil with over 10 parts of sand and less than 1 part of clay will be a (simple) *sand.* A soil with between 1 and 2½ parts of clay will be a *loam:* a (simple) *loam,* if sand and silt make up the residue in nearly equal proportions; a *sandy loam* if sand predominates in the residue; a *silty loam* if silt is predominant. A soil with between 2½ and 4 parts of clay will be a *clay loam:* either a (simple) *clay loam,* a *sandy clay loam* or a *silty clay loam,* depending on the content of the residue. And a soil with over 4 parts of clay will be a *clay*: again, either a (simple) *clay*, if sand and silt are equally represented in the residue, a *sandy clay* if sand predominates, or a *silty clay*, if silt predominates.

Of these ten soil classes, five—namely *sand*, *sandy loam*, *sandy clay loam*, *silty clay*, and *clay*—are found in the Oraibi valley (Table 1).

Sand soils occur on the upper and lower sand slopes, on the lower mesa top wherever the soil has received a high admixture of blown sand, and on sand dunes on the main valley floor; *sandy loams*, on the upper and lower mesa top, and extensively over the side valley slope. Traversing the side valley slope and carrying the run-off from the talus slope above to fans in the valley below, are numerous tributary watercourses; samples taken from fields sited on fans of this kind yield either a *sandy loam*, of composition rather close to that of the adjoining side valley slope, or else a *sandy clay loam*, with rather higher clay content. *Silty clays* occur in one location only: on talus slopes, where the soil represents the direct breakdown product of the underlying rock strata (beds of sandstone, with layers of consolidated mud and clay sandwiched between the beds). *Clay* soils, also, are found in one location only, on the alluvial flats of the main valley floor; a sample (H15) taken from the old flood plain of the main wash, near the lower windmill, yielded a sand content of 21%, silt 25%, and clay 54%.

By far the greater part, therefore, of the Oraibi valley is covered either by *sand* soils or by *sandy loams*, and the only extensive areas of non-sandy soil in the whole valley are:

a) two narrow belts circling the mesa and forming, respectively, the upper and lower talus slopes; and,

b) a belt of land on either side of the main wash, constituting the alluvial flats of the main valley floor.

Turning now to the plant associations found in the valley (as defined in the paper referred to above: *Plateau*, 41, 2:61–71), each of the three main soil classes (i.e. *sand, loam, clay*) corresponds to one association in particular: *sand* to the bush-mint association, *sandy loam* to the snakeweed association of the side valley slope, *clay* to the greasewood association of the main valley floor. Of the other plant communities, the black-sage association is commonly found on *sandy loams*, but may also occur on *sand* soils; the sagebrush association of the mesa top is only found on *sandy loams*; the rabbit-brush association, either on *sandy loams* or on *sandy clay*

loams; and the sagebrush association of talus slopes, only on *silty clay*. These are the correspondences we can observe on the ground; we have yet to determine the link between the physical composition of the soil, and the plant cover which it carries.

Some 50 years ago, Kearney and his colleagues carried out a survey (Kearney *et al.* 1914) of the vegetation and soils of the Tooele Valley, Utah. They found that, where the land had not been cleared by fire or cultivation, the natural vegetation of the valley consisted of a few easily recognizable plant communities, namely a sagebrush community, a 'mixed sand-hill' community, a shadscale community, and a greasewood-shadscale community; and further, that the distribution of these communities was largely determined by three factors: the moisture-retaining capacity of the soil, the salinity of the soil, and the depth to ground-water. These three factors I propose now to consider, in relation to the plant cover of the Oraibi valley.

In an arid region like that of the Hopi villages, not only is the annual rainfall low (9 to 11″ a year, on the average), but much of the rain that does fall is lost to the plants due to the very high rate of evaporation. The ability of the soil to hold on to the water that reaches it, and not to lose it to the ground-water, thus becomes critical for the vegetation that it can support. This moisture-retaining ability, known in Kearney's day as the 'moisture equivalent' of a soil and today as its 'field capacity', can be measured (in Kearney's day, by centrifuging a moist sample of the soil in sieved cups, today by equilibrating a moist sample at a pressure of 1/6 Atmosphere, and then determining the residual moisture). Not all the water, however, that is held in the soil is available to the plants that grow on it; at first, when the soil is damp, the cells of the plant root absorb the moisture freely, but as the soil becomes drier, it yields its moisture less readily, until a point is reached at which the osmotic pressure exerted by the cells is balanced by the suction exerted by the soil particles. This point is known as the 'wilting point', and the amount of water still held in the soil at that point as the 'wilting co-efficient'; this amount, also, can be measured (in Kearney's day, by growing a sunflower seedling in a moist sample of the soil until it began to wilt, today by equilibrating a moist sample at a pressure of 15 Atmospheres, and then determining the residual moisture). If, now, we subtract this figure from the 'moisture equivalent', we have a rough estimate of the amount of water actually available to the plant for a given soil; and it is this amount which chiefly determines the kind of vegetation that the soil can carry.

Chiefly, but not wholly: for there is another factor which may affect it, namely salinity. The high rate of evaporation which, in arid regions, makes the moisture-retaining capacity of the soil so critical for plant growth, has a further action: where drainage is restricted, it leads to the accumulation in the soil of soluble salts, and where these salts become sufficiently concentrated, they set a limit to the kind of vegetation that can survive there. The salts in question consist mainly of the cations Na^{+}, Ca^{++} and Mg^{++}, and the anions Cl^{-} and $-SO_4^{--}$. Ultimately, these salts are derived by weathering from primary minerals in the bedrock; but soluble salts are rarely sufficiently concentrated to form saline soils in their place of origin. Far more commonly, the salts are carried in solution—usually in the surface runoff—down into the valley, where they gradually build up in the soil due to the combined effect of poor drainage and high evaporation. Saline soils are thus restricted, in practice, to arid regions; and even in arid regions, they hardly ever occur on well-drained slopes.

Soil salinity is commonly measured as the *total soluble salt* (T.S.S.) content, expressed as a percentage: 1% being equivalent to 10,000 parts in a million. For practical purposes, soils are grouped into four classes, based on their agricultural potential:

soil class	description	T.S.S.
0	salt free	less than 0.15%
1	slightly saline	from 0.15 to 0.35%
2	moderately saline	from 0.35 to 0.65%
3	strongly saline	over 0.65%

Alternately, saline soils may simply be defined (Richards *et al.*, p. 46) as "those soils which contain soluble salts in such quantities that they interfere with the growth of most crops."

Salinity exerts its effect on plant growth, and so on the vegetational cover which a particular soil can carry, not by any directly harmful action of the salts themselves on the plant, but indirectly through the osmotic pressure exerted by the soil solution; increasingly, as it rises, this prevents the plant drawing from the soil the nutrients and moisture it requires for growth. There is thus no hard-

and-fast line at which growth suddenly stops; rather, as the concentration of salt in the soil rises, certain plants drop out of the running and those that survive become more and more stunted.

To return now to the relation between soils and vegetation in the Oraibi valley, and restricting ourselves to the effect of moisture supply on plant growth, differences in vegetational cover may evidently be due to one of three causes:

a) *surface conditions,* e.g. depth of soil, steepness of slope, exposure to sun and wind, volume of runoff that a given piece of land receives: all these factors affect the amount of water that actually reaches the subsoil;
b) *moisture-retaining capacity of the subsoil*: on this depends how much of the water that reaches the subsoil is held in it, and how much is lost to the ground water;
c) *salinity of the subsoil*: on this depends, in part, how much of the moisture that is held in the subsoil is actually available to the plant.

The figures for the moisture-retaining capacity and salinity of the five soil samples analyzed above are set out in Table 2. From these figures, read in conjunction with the surface conditions of the ground from which the samples were taken, certain general conclusions on the relation between soil and vegetational cover may be drawn.

Three principal soils—*sands, sandy loams,* and *clays*—are found in the Oraibi valley, and each of these soils, as we have seen earlier, carries its own distinctive plant community (or communities). Taking H7 as representative of *sand* soils, H10 as representative of *sandy loams,* and H15 as representative of *clay* soils, the 'moisture available to the plant' for the three classes stands in the approximate ratio 1 : 2 : 4; in other words, the *sandy loams* have roughly twice the moisture-retaining capacity of *sand* soils, and the *clay* soils roughly twice that of the *sandy loams.* This is in line with Kearney's findings for the soils of the Tooele Valley; and it seems reasonable to ascribe the differences between the bush-mint association, the associations that grow on *sandy loams,* and the greasewood association, to differences in the moisture-retaining capacity of their subsoils. As to the differences between the four communities that grow on *sandy loams,* these are to be looked for primarily in differences in the surface conditions of the zones where they are found: the difference between the sagebrush association of the mesa

TABLE 1

sample, and location	H7 upper sand slope	H10 side valley slope	H13 corn field on fan of tributary watercourse	H6 upper talus slope	H15 alluvial flats on main valley floor
appearance of sample	sandy soil, fine, dry:	sandy soil, fine, dry:	sand-and-clay soil, compact, damp:	green clay soil, friable, dry:	gray clay soil, friable, dry:
% of dry weight: coarse sand	77.4	56.4	34.8	8.4	7.8
fine sand	17.0	26.4	31.0	15.8	13.2
silt	2.1	5.0	11.4	34.9	25.0
clay	3.5	12.2	22.8	40.9	54.0
soil class	*sand*	*sandy loam*	*sandy clay loam*	*silty clay*	*clay*

TABLE 2

sample and soil class	H7 *sand*	H10 *sandy loam*	H13 *sandy clay loam*	H6 *silty clay*	H15 *clay*
field capacity (1)	6.0	12.8	19.7	23.5	33.1
capacity at wilting point (1)	1.8	5.1	8.5	10.9	16.8
moisture available to plant (1)	4.2	7.7	11.2	12.6	16.3
salinity (2)	.005 (*salt-free*)	.008 (*salt-free*)	.01 (*salt-free*)	.01 (*salt-free*)	0.15 (*slightly saline*)

(1) moisture content expressed as a percentage of the dry weight.
(2) expressed first as a percentage, and then (in brackets) using the terms for salinity employed by Buringh (1960).

top, and the black-sage association, being due to the greater depth of soil where black sage flourishes, and that between the snakeweed association of the side valley slope, and the rabbit-brush association on the fans of tributary watercourses, to the volume of surface run-off received by the one and not by the other.

The remaining plant community, the sagebrush association of talus slopes, occurs on *silty clay* soil, not far removed in composition from the *clay* soils that carry the greasewood association. As both soils may support a thin cover of fourwing saltbrush (*Atriplex canescens*), the difference between the two communities is likely to derive primarily from difference in surface conditions: in that the one is found on steep, exposed, well-drained slopes at a height of around 5,900 feet, and the other on the poorly-drained flats of the main valley floor (c. 5,400 feet). The slight salinity of the soil that carries the greasewood association may also play a part; and in this respect it is worth noting that at Chaco Canyon the *strongly saline* soil (salinity –0.75%) of the main valley floor (c. 6,100 feet) carries, besides greasewood and fourwing saltbrush (*Atriplex canescens*), two shrubs (*Lycium pallidum* and *Atriplex confertifolia*) which in the Oraibi valley only occur on talus slopes, while sagebrush and *Eriogonum aureum* are restricted—there, as in the Oraibi valley—to the side walls of the valley. This suggests that some members of the sagebrush community, e.g. sagebrush itself and *Eriogonum aureum*, are unable to tolerate even the slight degree of salinity present in the soil of the alluvial flats below Oraibi.

There remains one further question: why, when the fields on the old flood plain of the main wash were abandoned, the original greasewood cover failed to re-establish itself. This is probably to be ascribed to the last of Kearney's three factors: namely, to the fall in the level of the ground water consequent on the dissection of the wash (cf. on this point, Bryan 1928). But comparison with Chaco Canyon indicates that, in the course of time, the greasewood may succeed in re-colonising the alluvial flats from which it was cleared to make the corn fields.

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Stratigraphy and History of the Toroweap Formation (Permian) between Grindstone Canyon and Sycamore Canyon, Arizona

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Abstract. The Toroweap Formation in the area between Grindstone Canyon and Sycamore Canyon, Arizona, was deposited on a broad, shallow shelf adjacent to the shoreline marking the easternmost advance of the Toroweap sea. It is an area of transition between normal marine deposition to the west in the Aubrey Cliffs area, and predominately subaerial deposition to the southeast in the Sycamore Canyon-Oak Creek area. In most of the thesis area, the Toroweap may be divided into three members in ascending order: the Gamma, Beta, and Alpha Members (McKee 1938:13). The red Gamma Member was deposited in a low energy beach forming environment during transgression of the sea; the light-gray Beta Member was formed by the chemical precipitation of a calcareous ooze from highly saline, restricted waters of the extended sea; and the red Alpha Member was deposited in shallow, restricted basins that were alternately submergent and emergent during the overall regression of the sea. The middle limestone (Beta) member reaches a depositional pinchout just west of Sycamore Canyon. In the Sycamore Canyon area, the Toroweap is composed of the undifferentiated Alpha and Gamma Members.

INTRODUCTION

THE TOROWEAP FORMATION of early Permian age is exposed along the southern edge of the Colorado Plateau. Between Grindstone Canyon at the northwest end of the study area, and Sycamore Canyon at the southeast end, the Toroweap Formation undergoes a marked facies change from a sequence that consists largely of soft, friable rocks (mostly red-beds) that are separated by a resistant limestone unit, to a sequence that consists largely of soft, friable rocks which are cross-laminated, contorted, and lack the middle limestone unit (Fig. 1 and Table 1).

The purpose of this study was threefold: to trace, as far as possible, the three members of the Toroweap Formation as defined by McKee (1938); to make a detailed stratigraphic investigation of the facies change from a sequence of friable, thinly bedded and massive red-beds separated by a resistant carbonate unit, to a sequence of friable, cross-laminated, contorted red-beds that lack the car-